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ScienceDirect
Planetary and Space Science 54 (2006) 1315–1335
Planetary and Space Science
www.elsevier.com/locate/pss

Radio science investigations by VeRa onboard the Venus Express spacecraft

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Accepted 10 April 2006
Available online 24 August 2006

Abstract

The Venus Express Radio Science Experiment (VeRa) uses radio signals at wavelengths of 3.6 and 13 cm ("X"- and "S"-band, respectively) to investigate the Venus surface, neutral atmosphere, ionosphere, and gravity field, as well as the interplanetary medium. An ultrastable oscillator (USO) provides a high quality onboard reference frequency source; instrumentation on Earth is used to record amplitude, phase, propagation time, and polarization of the received signals. Simultaneous, coherent measurements at the two wavelengths allow separation of dispersive media effects from classical Doppler shift.

VeRa science objectives include the following:

(1) Determination of neutral atmospheric structure from the cloud deck (approximately 40 km altitude) to 100 km altitude from vertical profiles of neutral mass density, temperature, and pressure as a function of local time and season. Within the atmospheric structure, search for, and if detected, study of the vertical structure of localized buoyancy waves, and the presence and properties of planetary waves.
(2) Study of the H_2SO_4 vapor absorbing layer in the atmosphere by variations in signal intensity and application of this information to tracing atmospheric motions. Scintillation effects caused by radio wave diffraction within the atmosphere can also provide information on small-scale atmospheric turbulence.
(3) Investigation of ionospheric structure from approximately 80 km to the ionopause (<600 km), allowing study of the interaction between solar wind plasma and the Venus atmosphere.
(4) Observation of forward-scattered surface echoes obliquely reflected from selected high-elevation targets with anomalous radar properties (such as Maxwell Montes). More generally, such bistatic radar measurements provide information on the roughness and density of the surface material on scales of centimeters to meters.
(5) Detection of gravity anomalies, thereby providing insight into the properties of the Venus crust and lithosphere.
(6) Measurement of the Doppler shift, propagation time, and frequency fluctuations along the interplanetary ray path, especially during periods of superior conjunction, thus enabling investigation of dynamical processes in the solar corona.

Keywords: Radio Science; Radio occultation; Venus atmosphere; Venus ionosphere; Bistatic radar; Doppler shift; Solar corona

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0032-0633/$ - see front matter
doi:10.1016/j.pss.2006.04.032

1. Introduction

The Venus Express (VEX) Radio Science Experiment (VeRa) utilizes radio science (RS) techniques for studies of the Venus atmosphere, ionosphere, gravity field, and surface. Additional science objectives include radio sounding investigations of the solar corona and the near-Sun interplanetary medium. The VeRa instrument and its capabilities have been described in detail by Häusler et al. (2006). A suite of companion investigations on Mars Express (MEX) has been described by Pätzold et al. (2004).

VeRa investigations will be carried out by making use of the VEX spacecraft transponder, which is otherwise used for telemetry and tracking. This transponder has been augmented by the addition of an ultrastable reference frequency oscillator (USO) specifically to support the VeRa experiments.

RS investigations fall into three broad categories of experimentation and observation. First, for the study of planetary atmospheres and ionospheres, the spacecraft must be 'occulted' so that the gas or plasma lies between the radio source and receiver. In a typical occultation experiment conducted with an orbiter, the spacecraft sequentially passes behind the ionosphere, the neutral atmosphere, and finally the planetary disk as seen from the tracking station on Earth; it then re-emerges in the reverse sequence. During an occultation event one 'senses' the media of interest—atmosphere and ionosphere—by their effects on the radio signal (Fjeldbo and Eshleman, 1969; Fjeldbo et al., 1971; Eshleman, 1973). For the case of coherent, dual-frequency transmission, this experiment allows the separation of dispersive and non-dispersive media effects from classical Doppler effects.

Second, oblique-incidence scattering investigations using propagation paths from a spacecraft via a planetary surface to an Earth-based station can be used to explore the surface properties including the microwave scattering function. Such investigations are commonly referred to as "bistatic radar", because the transmitter (the spacecraft) and receiver (the ground system on Earth) are separated by significant angular distances and/or ranges. Magellan observations in the early 1990s greatly improved our understanding of the microwave emissivity, reflectivity, and topography of the Venus surface (Pettengill et al., 1992; Ford and Pettengill, 1992; Tyler et al., 1992), but some of the detailed relationships among these properties remain unresolved (Carter et al., 2001).

Third, "gravity" experiments use precision measurements of the distance and velocity along the line of sight between the spacecraft and Earth to detect perturbations in the gravity field in order to determine the distribution of mass within Venus. The spherical harmonic gravity field of Venus was determined to degree and order 180 by Barriot et al. (1998) and Konopliv et al. (1999), but questions concerning the properties of the Venusian crust and lithosphere below special target areas still remain open.

Radio occultation measurements strongly complement and extend other spacecraft and Earth-based remote-sensing observations, such as infrared spectroscopy, which provide detailed information on atmospheric constituents and vertical structure at low resolution over wide regions by instrument scanning. Greatly improved results are obtained by combining radio-occultation measurements with such supplementary observations.

In all cases, a RS experiment relies on the extreme frequency stability of the signals employed and measured. VeRa will be the first RS experiment at Venus to employ an ultra-stable reference frequency source (USO) on board the spacecraft.

A summary of the observation possibilities and scientific objectives, including RF-transmission modes of the VEX spacecraft has been presented in Häusler et al. (2006).

2. Radio sounding of the neutral atmosphere

2.1. Background

The Venusian atmosphere consists mainly of CO_2 (~96.5%) and N_2 (~3.5%) with small amounts of other gases (see Fig. 1). The lower and middle atmosphere display a strong zonal wind structure with a period of 4–5 days ("super-rotation", in the sense of planetary rotation). Venus is shrouded by a 20 km thick cloud layer; the surface temperature is ~735 K (Seiff et al., 1985; Moroz and Zasova, 1997). There is no sublimation/condensation of the atmosphere as is the case for Earth and Mars (Saunders, 1997).

The atmosphere is critically refractive below ~32.3 km making lower altitudes inaccessible to radio occultations. VeRa will be able to characterize the global density and thermal structure above ~40 km as a function of altitude, latitude, and local time (Häusler et al., 2006). Atmospheric observations, if made in sufficient number, can reveal the nature of the propagating atmospheric waves and can contribute to the understanding of angular momentum transfer in the atmosphere.

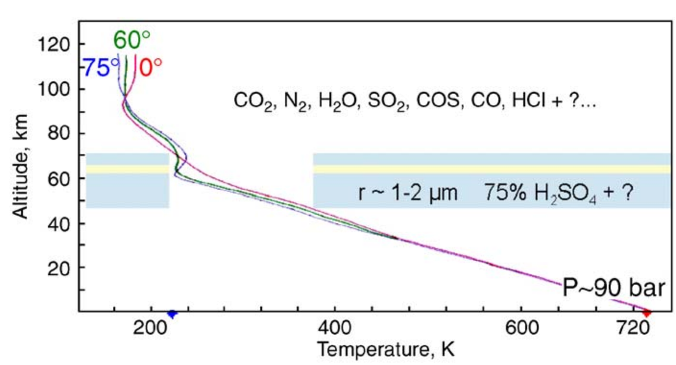

Fig. 1. Representative temperature structure of the lower and middle atmosphere of Venus at three latitudes (0°, 60°, and 75°). Indicated are the locations of structured clouds and the main constituents of the atmosphere with the dominating molecules CO_2 and N_2. It is assumed that micron size droplets of 75% H_2SO_4 form parts of the cloud layers (Titov et al., 2001).